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USING OPTICAL STEREO DATA TO ASSESS GLACIER MASS CHANGES IN THE HIGH MOUNTAINS OF ASIA SINCE THE 1960S

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1. INTRODUCTION

Glaciers are key indicators for climate variability in high mountains where long-term climate measurements are rare. In addition, glacier melt water contributes to river discharge. Glacier area and length changes are comparatively easy to measure using multi-temporal satellite images but only the glaciers mass budget shows an almost direct signal to climate. However, long-term in-situ measurements of glacier mass budgets are currently rare in the Central Asian mountains like the Tien Shan while there is no measurement longer than 10 years existing in the Himalaya or Tibet [3, 6]. Some earlier measurements in the Tien Shan were interrupted after the collapse of the Soviet Union and new investigations have just started or are planned. Remote-sensing derived multi-temporal geodetic mass change estimations are a suitable tool to assess glacier mass changes in remote mountain areas and to cross-calibrate existing time series or extend them in time [7]. The earliest available stereo satellite data are the U.S. reconnaissance imagery Corona KH-4 and KH-4a and 4b. These can have a spatial resolution from up to 2 m and date back to 1962 [5]. Terra ASTER, SPOT5 or Cartosat imagery are suitable recent data with stereo capability. We present case studies from the Northern Tien Shan in Kyrgyzstan, Central Tien Shan in Xinjiang/China, and Khumbu Himalaya in Nepal.

2. DATA AND METHODS

We used KH-4 (year 1962), KH-4A (1970), ASTER (2002), and Cartosat-1 data (2007) to generate a time series of digital terrain models (DTMs) for the glaciers at Mt. Everest/Nepal Himalaya and KH-4 (1962), KH-4B (1971) and the SRTM DTM (2000) for the Ala Archa Valley (Northern Tien Shan/Kyrgyzstan). For the Aksu-Tarim Catchment (Central Tien Shan/Xinjiang Uighur Autonomous Region/China), we selected KH-9 Hexagon (1976), SRTM3 (2000), and SPOT-5 (2009) data. After image enhancement procedures, encompassing the Wallis Filter and Histogram Equalization, the contrast was sufficient to generate DTMs of good quality. However, some gaps and inaccuracies still remain in areas with shadows and

snow cover like in parts of the accumulation areas of the glaciers. Careful co-registration and relative adjustments were necessary due to tilts and shifts especially in the DTMs generated from Corona and Hexagon data. Horizontal offsets between multi-temporal DTMs were corrected using the relation between planimetric shifts and the corresponding slope and aspect values at a certain pixel position [4]. Tilts could be successfully adjusted based on trend surfaces calculated from the deviation in non-glaciated stable terrain and the shifts were addressed by minimizing the standard deviation of the non-glaciated terrain [5, 2]. The uncertainty of the calculated glacier elevation changes, estimated based on the standard error in the case of small sample sizes or the 68.3 % quantile in the case of large sample sizes with a non-normal distribution of the non-glaciated terrain, was less than 6 m. An ice density of 900 kg/m^3 was assumed for transferring the volume change to glacier mass changes.

3. RESULTS AND CONCLUSIONS

The relative accuracy of the generated DTM was sufficient to estimate glacier volume loss in the different study areas. Volume loss occurred on average at all of the glaciers despite partly thick debris cover. The specific mass loss of the glaciers at Mt. Everest was $0.32 \pm 0.08 \text{ m water equivalent (w.e.) a}^{-1}$ ($0.36 \pm 0.09 \text{ m a}^{-1}$ surface lowering) for the period 1970-2007. No significant changes could be detected for 1962 until 1970 [2]. Significant downwasting was also found for the glaciers in Ala Archa Valley/Kyrgyzstan. The volume loss is especially visible at the tongues (Fig. 1).

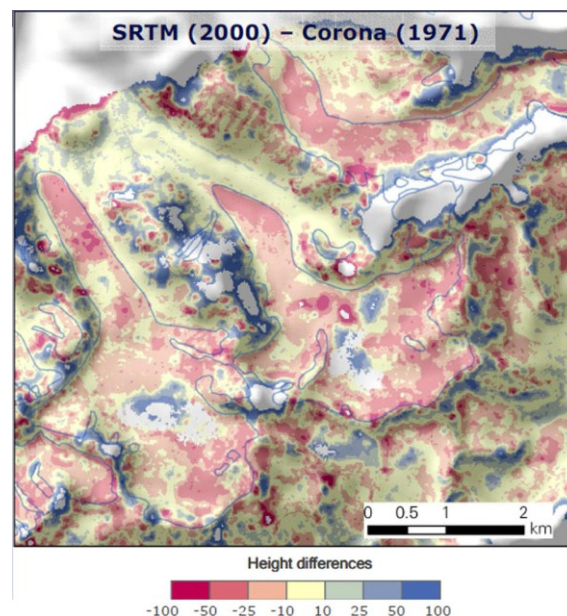


Figure 1: Height difference of the 1971 Corona DTM and the 2000 SRTM DTM for selected glaciers in the Ala Archa Valley/Kyrgyzstan. The surface lowering is clearly visible especially at the glacier tongues.

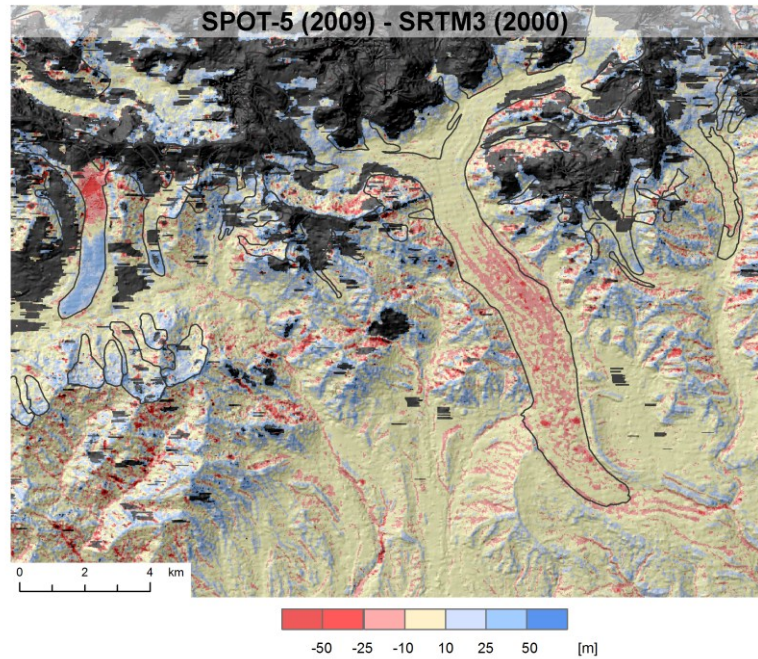


Figure 2: Height difference of the 2000 SRTM3 DTM and the 2009 SPOT-5 DTM for selected glaciers in the Aksu-Tarim Catchment/China. Glacier mass gains and losses are visible.

The specific mass budget is $-0.40 \pm 0.12 \text{ m w.e. a}^{-1}$ between 1971 and 2000 with a possible slight mass gain between 1964 and 1971. Although the gain is not significant for the 1964-1971 due to high uncertainties, it is consistent with modelling results for Golubina Glacier [1] which is situated in the investigated valley. Similar mass budgets as for the Ala Archa Valley were revealed for the glaciers in the Aksu-Tarim catchment. The overall mass budget for 1976-2009 is $-0.35 \pm 0.15 \text{ m w.e.a}^{-1}$. In the recent years a slightly accelerated loss of $-0.42 \pm 0.19 \text{ m w.e.a}^{-1}$ could be determined. However, some small glaciers show mass gains at their tongues. Positive mass balances of around $1.00 \pm 0.19 \text{ m w.e.a}^{-1}$ since 1999 along with a surface lowering in the accumulation areas of more than -20 m are indicators for glacier surges (Fig. 2).

These results confirm that the recently published methodology for assessing glacier mass changes using stereo Corona data for the Mt. Everest area [2, 5] can successfully be transferred to other high mountain regions and that stereo Corona and Hexagon images were found to be suitable to extend time series of multi-temporal DTMs analysis back in time. Work is underway to extend the investigated glaciers to further regions in high Asia within the BMBF and DFG funded projects “TiP, WET, SuMaRiO and Aksu-Tarim-RS” and the ESA funded project “Glaciers_cci”.

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